A Rotating Source Polarization Measurement Technique Using Two Circularly Polarized Antennas

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***Abstract*—This paper combines the standard two-antenna gain measurement technique with the rotating source method for measuring the polarization ratio and tilt angle of the polarization ellipse of a circularly polarized antenna.**

The technique is illustrated with two identical helical antennas, one for the source and one for the antenna-under-test (AUT), facing each other. Measurements of the voltage transfer ratio are made over one 360 degree on-axis rotation of the source while the AUT remains stationary. The rotation causes the phase of the electric field of the principal polarization to rotate in one direction and the phase of the cross polarization to rotate in the opposite direction. A Discrete Fourier Transform (DFT) of the data from a single rotation is insufficient to resolve the two polarization components. Leakage from the principal polarization will most likely cover up the low-level opposite polarization signal. However, the DFT resolution can be artificially increased by appending to the measured data, precisely M-1 copies of the data. Now the polarization components will be separated by 2M revolutions. Application of a heavy weighting function to the augmented data and a phase compensation to the DFT allows a clear determination of the amplitude and phase of the on-axis principal and cross polarization components.

The technique was verified by electromagnetic simulations and by measurements in an anechoic chamber with two 6-turn 5.8 GHz helical antennas separated by 4 feet. There was very good agreement between the simulations and measurements of the polarization ellipse tilt angle and a -20 dB polarization ratio.

***Keywords*– Circular polarization measurements; helical antenna**

I. Introduction

Circularly polarized (CP) antennas are often used in communication systems either to mitigate multipath effects or to double the data handling capacity by polarization diversity. The antenna parameters of interest are the axial ratio, the tilt angle of the polarization ellipse and, if not self-evident, the rotational sense of an antenna.

More than forty years ago Newell [1] and Joy [2] independently developed the three-antenna method for measuring polarization parameters. Although this technique has become a standard test procedure for antennas [3], it is rather cumbersome and has not found widespread use. Jones and Hess [4] included a single-point Fourier transform in the three-antenna method primarily for the benefit of improving the measurement accuracy. In this paper we also employ a Fourier transform, but we use it to separate the orthogonal polarization components.

Ten years later, another method for measuring the polarization ratio of circularly polarized antennas with a rapidly rotating linearly polarized source antenna was developed by Greene and Thomas [5]. It required a source antenna with high polarization purity. The axial ratio of the polarization ellipse was determined from the ripple in the voltage received by the continuously rotating antenna-under-test (AUT). This technique cannot be used to determine the tilt angle or the sense of polarization.

Except for some improvements in accuracy [6], [7], no new polarization measurement techniques appear to have been published since that time.

In this paper we combine the technique described in [4] with a source rotation [5] and apply it to the two-antenna geometry which is commonly used for gain measurements [3]. We will show that if the source antenna and the AUT are identical circularly polarized antennas, then, by processing s-parameters from one 360 degree antenna rotation with a suitable Fourier transform, we will be able to determine the polarization ratio as well as the tilt angle of the polarization ellipse of the antenna.

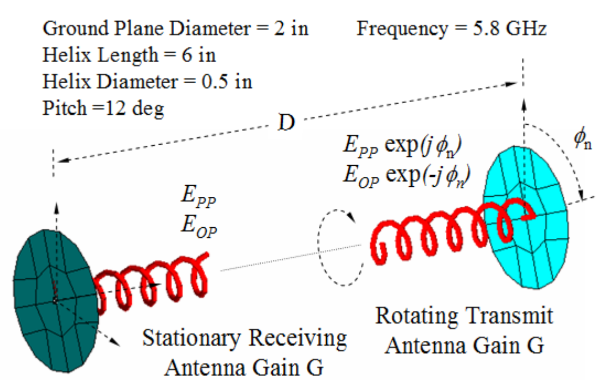

Fig. 1. Antenna Geometry for Polarization Measurements

II. Theory

Consider two identical circularly polarized antennas arranged as shown in Fig. 1 for on-axis antenna gain mea-

surements [3]

$$G = \frac{4\pi D}{\lambda} |s_{21}|, \tag{1}$$

where λ is the wavelength. We assume that the antenna separation D meets the far-field condition, and the complex voltage transfer ratio s_{21} is measured with a network analyzer. The antenna gain G is the total gain. That is, since

$$|s_{21}| = |s_{21}|_{RH} + s_{21}|_{LH}|, \tag{2}$$

no distinction can be made between the gain contribution due to right-hand (RH) or left-hand (LH) polarization. Usually, one polarization, which we will refer to as the principal polarization (PP), is dominant. However, in certain applications, the opposite polarization (OP) cannot be ignored.

We will now describe a method for separating the PP and OP components of s_{21}. The total electric field at the receive antenna, $\overline{E}_R$, can be represented by two orthogonal circularly polarized components: $E_{PP}|_R$ and $E_{OP}|_R$. In vector form [4]

$$\overline{E}_R = \begin{bmatrix} E_{OP}|_R \\ E_{PP}|_R \exp(j\delta_R) \end{bmatrix}, \tag{3}$$

where δ_R is the relative phase between the PP and OP signals. The circular polarization ratio ρ_R and the tilt angle τ_R of the polarization ellipse are defined by [8]

$$\rho_R = \left| \frac{E_{OP}|_R}{E_{PP}|_R} \right| \text{ and } \tau_R = \frac{\delta_R}{2}. \tag{4}$$

We propose to measure the polarization parameters by assuming that the receive antenna is fixed and the transmit antenna can be mechanically rotated in N steps about the line-of-sight axis through a full 360 degrees. We know that if a CP antenna is mechanically rotated about its axis by an angle ϕ, the mechanical rotation shifts the electrical phase of the PP polarization by ϕ degrees in one direction and the phase of the OP polarization by the same amount in the opposite direction [4], [9]. Thus the electric field of the transmit antenna becomes

$$\overline{E}_T = \begin{bmatrix} E_{PP}|_T \exp(j\phi_n) \\ E_{OP}|_T \exp(j\delta_T - j\phi_n) \end{bmatrix}. \tag{5}$$

where

$$\phi_n = \frac{2\pi n}{N-1}, \qquad n = 1, 2, \ldots, N.$$

Since the transmit and receive antennas are identical, the polarization ratios and the magnitude of the relative phase shifts will be the same

$$\rho = \rho_T = \rho_R. \text{ and } \delta = \delta_R = -\delta_T \tag{6}$$

However, in a common coordinate system in which the antennas are facing each other, the phase shifts have opposite signs.

We now calculate the normalized voltage transfer ratio

$$s_{21}(n) = \frac{\overline{E}_T \overline{E}_R^*}{|\overline{E}_T|\,|\overline{E}_R|}. \tag{7}$$

where * means conjugate. Substituting (3), (5) and (6) into (7) yields

$$s_{21}(n) = \exp(j\phi_n) + |\rho^2| \exp(j2\delta - j\phi_n). \tag{8}$$

A discrete Fourier transform (DFT) of (7)

$$\mathcal{F}(k) = \frac{1}{N}\sum_{n=1}^{N} s_{21}(n) \exp\left[\frac{2\pi ikn}{N}\right], \; -\frac{N}{2}+1 \le k \le \frac{N}{2} \tag{9}$$

can be evaluated in two parts

$$\mathcal{F}(k) = \mathcal{F}_{PP}(k) + \mathcal{F}_{OP}(k)] \tag{10}$$

where

$$\mathcal{F}_{PP}(k) = \frac{1}{N}\sum_{n=1}^{N} \exp\left[\frac{2\pi jkn}{N} + j\phi_n\right] \tag{11}$$

$$\mathcal{F}_{OP}(k) = \frac{|\rho|^2 \exp(j2\delta)}{N}\sum_{n=1}^{N} \exp\left[\frac{2\pi jkn}{N} - j\phi_n\right]. \tag{12}$$

It can be shown [10], that (11) and (12) each have only one non-zero component

$$\mathcal{F}_{PP}(k) = \begin{cases} 1 & k = 1 \\ 0 & \text{otherwise} \end{cases} \tag{13}$$

$$\mathcal{F}_{OP}(k) = \begin{cases} |\rho|^2 \exp(j2\delta) & k = -1 \\ 0 & \text{otherwise} \end{cases}. \tag{14}$$

Theoretically, since the PP and OP components are separated in frequency by three FFT bins, all polarization parameters could be determined from (9). Jones and Hess [4] made the same observation but did not elaborate on its implications.

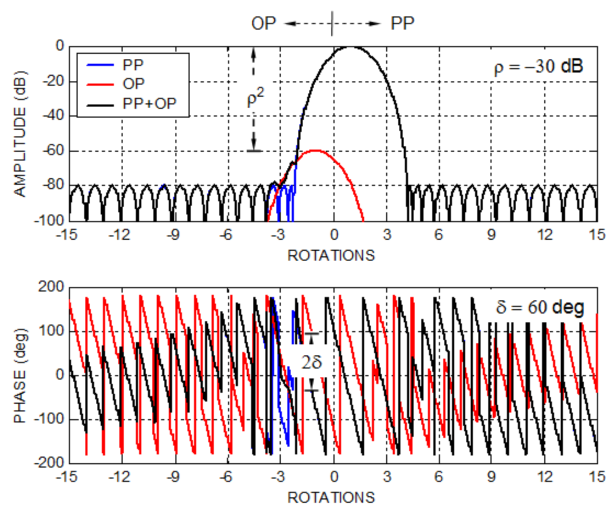

Fig. 2. DFT of a Single 360^0 Source Rotation

In Fig. 2 we evaluated (9), (11) and (12) for $\rho = -30$ dB and $\delta = 60$ deg. We made the DFT peaks and nulls more apparent by interpolating the DFTs with zero padding [10]. We note that the OP component is reduced by the square of the polarization ratio. Thus, the sidelobe level in the DFT must be twice as low, in dB, as the lowest expected polarization ratio. For example, a heavy 80 dB Chebyshev weighting function

applied to (8) would allow detecting polarization ratios as low as -40 dB. However, Fig. 2 illustrates that leakage from the PP component will cover up the OP component even for very modest polarization ratios.

We conclude that data from a single rotation of a helical antenna will not resolve the closely spaced polarization components, particularly if their amplitudes are greatly unequal.

We will now correct this limitation. The original data set contains N measurements uniformly spaced over exactly one mechanical revolution. Except for some improvements in the measurement quality due to averaging, there is no advantage in making measurements over multiple revolutions. However, we can artificially improve the frequency resolution by appending to the original data $M-1$ copies of the measurements. The expanded data set $\widetilde{s}_{21}$ contains MN samples, that is

$$\widetilde{s}_{21}(n+Nm) = s_{21}(n), \quad \begin{array}{l} n = 1, 2, \ldots, N \\ m = 0, 1, \cdots, M-1 \end{array} . \tag{15}$$

An example of the phase progression of the expanded data with $M = 9$ is shown in Fig. 3.

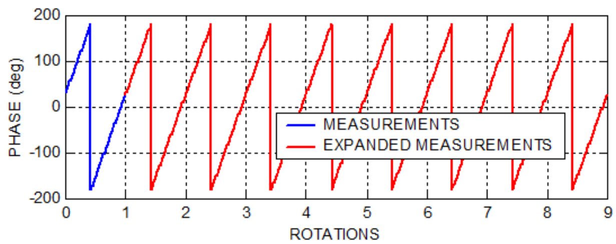

Fig. 3. Phase of Expanded Data $\widetilde{s}_{21}$

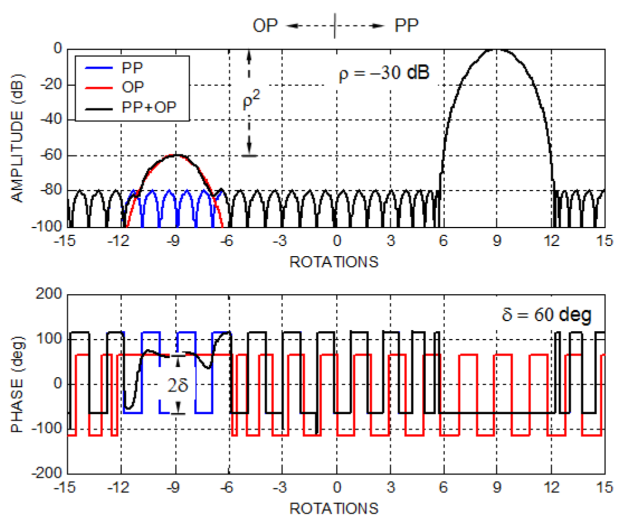

Fig. 4. DFT of Expanded Data

The DFT frequency bins of $\widetilde{s}_{21}$ extend from $-NM/2+1 \leq k \leq NM/2$ and PP and OP peaks will occur exactly at

$$\widetilde{\mathcal{F}}_{PP}(k) = \begin{cases} 1 & k = M \\ 0 & \text{otherwise} \end{cases} \tag{16}$$

$$\widetilde{\mathcal{F}}_{OP}(k) = \begin{cases} |\rho|^2 \exp(j2\delta) & k = -M \\ 0 & \text{otherwise} \end{cases} . \tag{17}$$

With this data expansion, Fig. 4. illustrates that the PP and OP components of (15) are now be clearly separated.

The rapidly changing phase of the DTF in Fig. 2 makes it very difficult to determined the phase of the PP and OP components. A small error in locating the DFT peak amplitude can result in a large phase error. Therefore, in Fig. 4, we applied to the expanded DFT a phase compensation [11]

$$c(k) = \exp[\frac{j\pi(NM-1)k}{NM}] \tag{18}$$

which renders the phase under the DFT peaks constant.

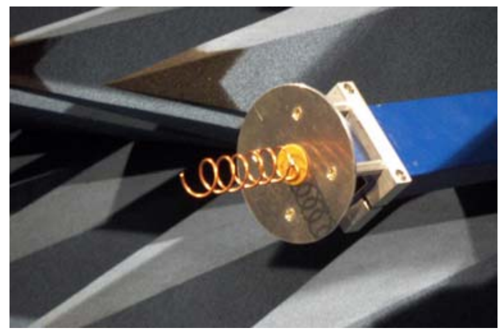

Fig. 5. Helical Antenna Mounted on Roll Axis

III. Experimental Results

The technique was verified with two six-turn helical antennas designed as specified by [12] to operate at 5.8 GHz. The dimensions are given in Fig. 1. A quarter wave impedance transformer was used for impedance matching.

The measurements were carried out with a near-field measurement system in an anechoic chamber at the University of Maine. One of the helical antennas was attached to the near-field scanner roll axis as shown in Fig. 5. The roll axis rotation was limited to ± 180 degrees.

An example of the expanded $\widetilde{s}_{21}$ measurements at 5.8 GHz is shown in Fig. 6. The linear phase progression has been removed from the phase measurements to show a ripple. The corresponding polarization ratio and polarization tilt angle can be extracted from the DFT in Fig. 7.

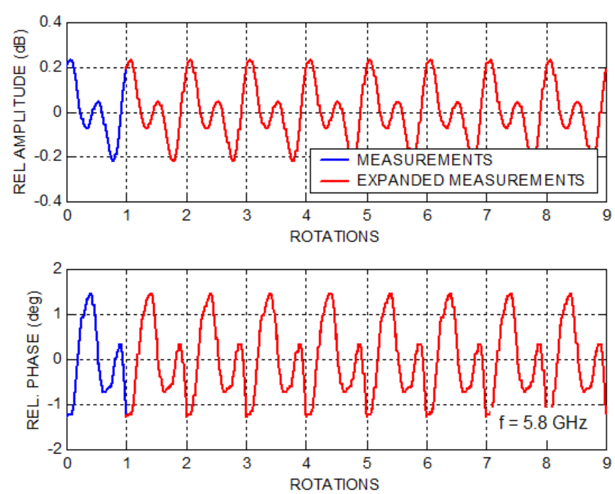

Fig. 6. Example of Expanded $\widetilde{s}_{21}$ Measurements

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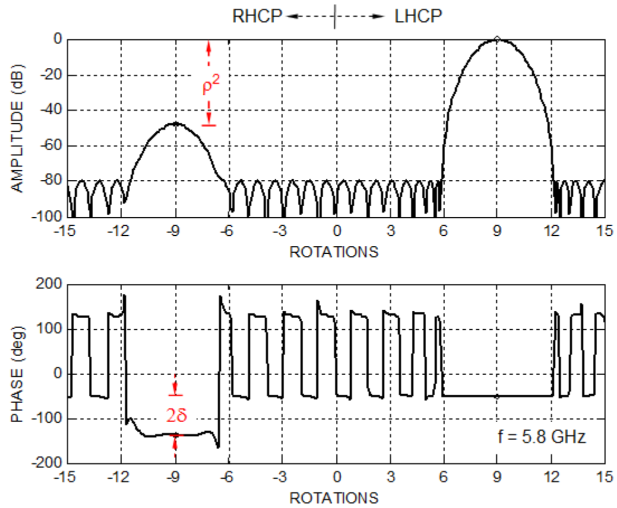

Fig. 7. DFT Example of Extended Measurements

The frequency dependence of measured polarization ratios and tilt angles is summarized in Fig. 8. We obtained substantially the same result from PP and OP antenna patterns of an individual helical antenna simulated with WIPL-D [13].

Obviously, the principal and opposite antenna gains could also be calculated by substituting the un-normalized values of $\widetilde{s}_{21}|_{PP}$ or $\widetilde{s}_{21}|_{OP}$ into (1).

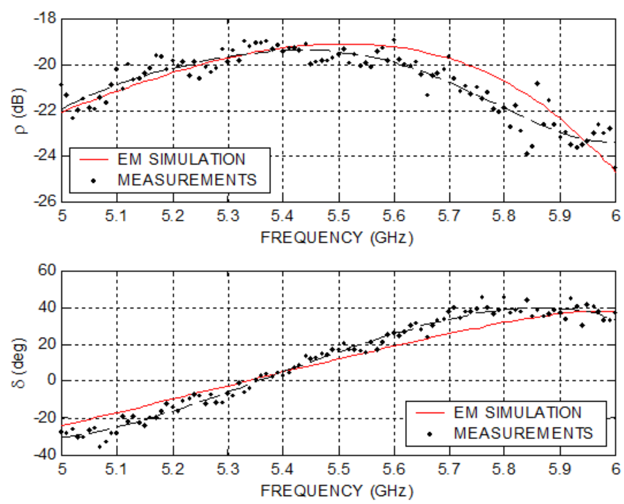

Fig. 8. Polarization Ratio and Polarization Ellipse Tilt Angle

IV. CONCLUSIONS

An augmentation of the two-antenna gain measurement technique has been presented for determining the polarization ratio and polarization ellipse tilt angle of a helical antenna. The technique exploits the periodicity of a Fourier transform and a 360 degree mechanical antenna rotation to separate the principal and opposite polarization components. It was verified by measurements and simulations.

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